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Abstract

Choke-mode damped structures are being studied as an alternative design for the accelerating structures of main linacs of the compact linear collider (CLIC). Choke-mode structures have the potential for much lower pulsed temperature rise, and lower cost of manufacture and fabrication. A new kind of choke-mode structure was proposed and simulated by Gdfidl. This structures has comparable wakefield damping effect as the baseline design of CLIC main linacs.

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CHOKE-MODE DAMPED STRUCTURE DESIGN FOR THE CLIC MAIN LINAC*

Hao Zha, Huaibi Chen†, Chuanxiang Tang, Wenhui Huang
Tsinghua University, Beijing CN-100084, P.R.China
Jiaru Shi‡, Alexej Grudiev, Walter Wuensch
CERN, Geneva CH-1211, Switzerland

Abstract

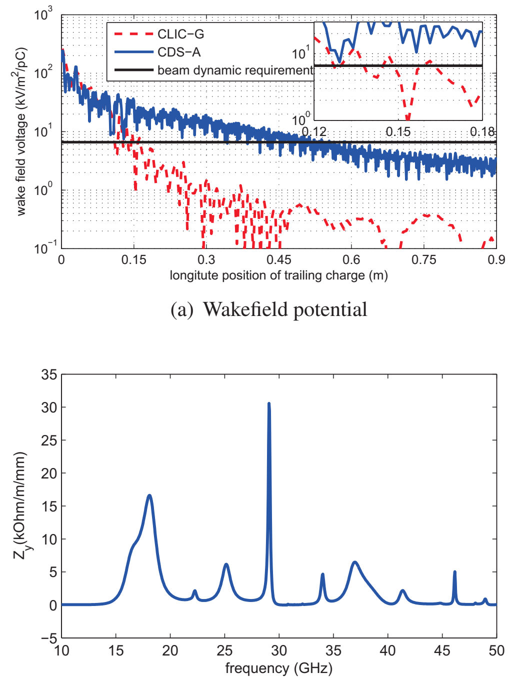
Choke-mode damped structures are being studied as an alternative design for the accelerating structures of main linacs of the compact linear collider (CLIC). Choke-mode structures have the potential for much lower pulsed temperature rise, and lower cost of manufacture and fabrication. A new kind of choke-mode structure was proposed and simulated by Gdfidl. This structures has comparable wakefield damping effect as the baseline design of CLIC main linacs.

INTRODUCTION

X-band normal conducting accelerating structures with waveguide damping design are now chosen as the nominal design of CLIC main linac (CLIC-G) [1]. The waveguide damping scheme can provide strong damping to all higher order dipole modes, make the transverse kick at position of second bunch less than 6.6kV/pC/m/mm, which is required by beam dynamics. However, high pulsed temperature rise is a critical issue for waveguide damped structure, which refers a high breaking down rate.

Choke-mode structure [2] has lower surface magnetic field and the potential to reduce the total manufacturing cost since only turning is needed. Given these benefits, the choke-mode structures are being studied as one of the alternative designs for the CLIC main linacs, under the collaboration between CERN and Tsinghua University in China. A structure with 24 tapered cells with choke-mode damping was designed. The iris radii of first cell and last cell are 2.35mm and 3.15mm, respectively, which are the same as the nominal CLIC-G design. The gap of radial line and choke is 1mm. Radial choke was used in this structure because the length of the cell at $2\pi/3$-mode is not enough for hosting a coaxial choke[3]. We had named choke-mode structure series as "CDS" for future reference, and this structure was named "CDS-A".

The wakefield simulation results of "CDS-A" in Gdfidl [4] are shown in Fig 1. The wakefield potential (Fig 1(a)) at the position of the second bunch is 20∼30 V/pC/mm/m, much higher than that of waveguide damping design. The corresponding impedance spectrum (Fig 1(b)) shows a very high peak near 29GHz. This is a weakly damped mode and dominates the total transverse kick at second bunch.



(a) Wakefield potential

(b) Wakefield impedance spectrum

Figure 1: Simulation results of CDS-A.

NEW CHOKE DESIGN

As presented in [2], the choke structure fully reflects not only the fundamental mode, but also the higher order modes at odd multiples of the accelerating frequency. For the radial choke structure in "CDS-A", the second fully reflected frequency should be approximately 29GHz and there is accidently a dipole mode nearby. This may be the reason of very high peak shown in Fig 1(b).

A model structure is proposed for quick simulation in order to find the fully reflected frequencies and study possible methods to tune them. As shown in Fig 2, the structure has a radial line with a choke, and connected to a coaxial line, which is defined as a wave port in simulation. The outer layer of this radial line is filled with absorber. The reflection at the wave port is simulated in HFSS [6], then the reflection, S_{11}, by the choke is obtained after calibration.

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† chenhb@mail.tsinghua.edu.cn
‡ Jiaru.Shi@cern.ch

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This is similar as the reflecting test in [5].

The simulation results of this test structure for the choke geometry of "CDS-A" is shown in Fig 3. The zero absorption points in the curve are fully reflected frequencies. The second zero-point is at 29.3GHz. In order to avoid high Q of dangerous modes, the second fully reflected frequency must be moved to a higher frequency which is far away from all dipole modes with high $(R/Q)_\perp$.

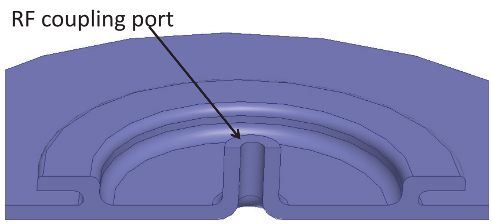

Figure 2: Structures to test the reflection at choke.

A new type of choke structure shown in Fig 3 was proposed to make a higher second reflecting frequency. We named this as "bottle choke" or "two-section choke", similar as the choke structure proposed in [7]. It has two parts joint together, one has a wider gap and the other is narrower. If we model the the section as two transmission line (show in Fig 3), they have different characteristic impedance which is proportional to the gap size. The joint plane can be equivalent as an impedance transformer with ratio K.

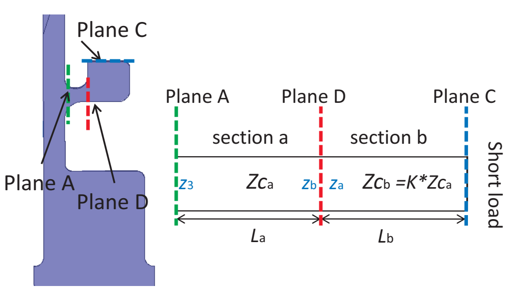

Figure 3: Two sections design for choke.

The impedance of the choke z_3 can be calculated based on transmission line theory.

$$\begin{aligned} z_\mathrm{b} &= j\tan(kL_\mathrm{b}) \\ z_\mathrm{a} &= Kz_\mathrm{b} = jK\tan(kL_\mathrm{b}) \\ z_3 &= \frac{z_\mathrm{a} + j\tan(kL_\mathrm{a})}{jz_\mathrm{a}\tan(kL_\mathrm{b}) + 1} \\ &= j\frac{\tan(kL_\mathrm{a}) + K\tan(kL_\mathrm{b})}{1 - K\tan(kL_\mathrm{a})\tan(kL_\mathrm{b})} \end{aligned}$$

If $z_3 = \infty$ the frequency will be fully reflected. After solving the equation we will get the the fully reflected frequencies. In the case that two sections have same length, we have:

$$\frac{f_2}{f_1} = \frac{\pi}{\tan^{-1}(K^{-1/2})} - 1, \tag{1}$$

where f_1 is the first fully reflected frequency which is the accelerating mode, f_2 is the second fully reflected frequency. For the ordinary coaxial choke, $K = 1$, so $f_2 = 3f_1$. For two sections choke, $K > 1$, so we have higher second fully reflecting frequency. For example, if $K = 3$, $f_2 = 5f_1$.

Fig 4 shows the simulation results of two-section choke with $K = 2$. The second fully reflected frequency is moved to sim45GHz. But it is also observed in this curve that the absorption to lower frequency from 12GHz to 20GHz is reduced. The first-passpand dipole modes near 17GHz have very high $(R/Q)_\perp$. So it is very dangerous to lose the strong absorption at lower frequency.

In order to solve this problem, section "a" of the choke is designed to have a narrower gap than the inner radial line (shown in Fig 5(a)), referred to as "the thin-neck design". Then the joint plane of section "a" and the radial line is another impedance transformer. The reactance of the dipole modes will be divided by the ratio M (M is the gap of radial line divided by gap of section "a"), so reflection will be lower. But there is a side effect of the "thin-neck" design: the field at section "a" will be multiplied by the ratio M and may cause a high RF break down rate. So the ratio M is limited. The simulation result of two-section choke with thin-neck design is also show in Fig 4, with the configuration of $K = 2, M = 3$.

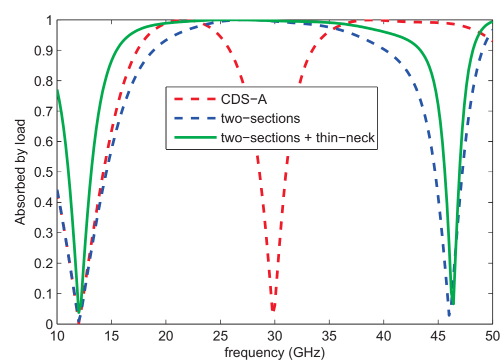

Figure 4: Absorption curve. Absorption in the load is given by $\sqrt{1 - S_{11}^2}$.

Another way to increase the absorption to the first dipole modes is adding a matching step at outer radial line (see Fig 5(b)). The reactance of the step can counteract the reactance of choke for lower pass-band dipole modes. However, this design also increase the reflection of some modes at other frequencies. But for total optimization, if these modes do not have high $(R/Q)_\perp$, the damping effect is still increased. This method is used together with the "thin-neck" design to achieve better results. Fig 6 shows the results of choke with matching step and without matching step, the configuration of this choke is $K = 5/3, M = 1.5$.

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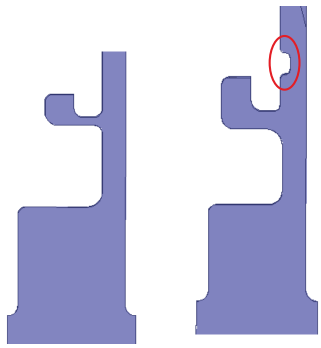


(a) Thin-neck (b) Matching step

Figure 5: Two methods to increase the absorption of the first-passband modes.

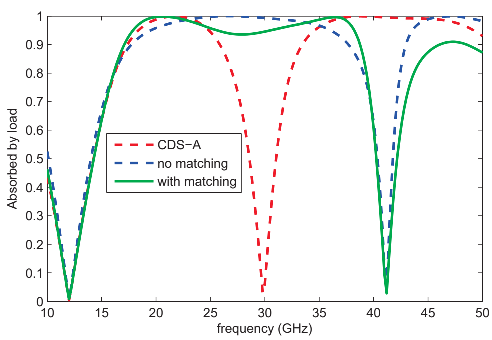
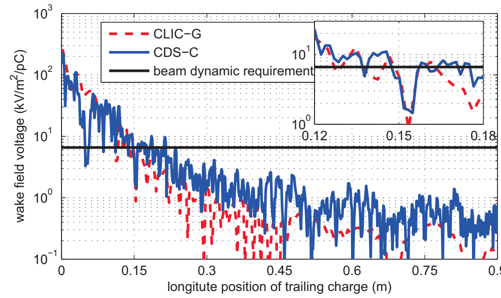


Figure 6: Absorption curve.

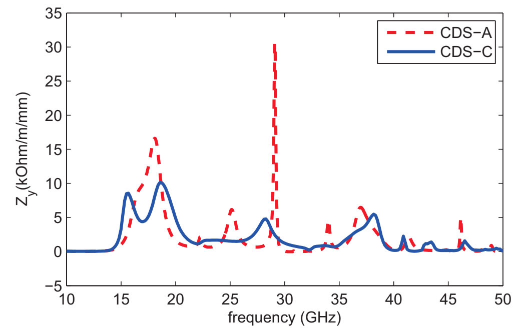
WAKEFIELD DAMPING IN NEW CHOKE STRUCTURES

With all these new features introduced in section employed to maximize the damping effect to higher order modes, we come with a new structure design named "CDS-C", which also has 24 tapered cells but with the new choke. Wakefield simulation results of "CDS-C" using Gdfidl are shown in fig 7(a). The total transverse kick at second bunch is about about 4V/pC/m/mm, which is comparable to the waveguide damping design of CLIC-G.

The impedance spectrum is also given in fig 7(b): the peak near 29GHz is now much lower and impedance of other modes are reduced as well. Two peaks near 17GHz are observed in this spectrum representing the first-passband dipole modes. The frequency difference of these two modes are optimized to ~3GHz by changing the radii of the main cavity and the inner radial line. The 3GHz separation of these two modes will make them beat at the position of second bunch at 0.15m or 0.5ns, and produce smaller transverse kick.



(a) Wakefield potential



(b) Wakefield impedance spectrum

Figure 7: Simulation results of CDS-S.

CONCLUSION

A new type of choke structure including the new features as "two-sections", "thin-neck design" and "matching step" is proposed to achieve better wakefield damping effect. A structure with 24 tapered cells and this new choke has been designed and named as "CDS-C". The wakefield potential of "CDS-C" at the position of the second bunch is about 4V/pC/m/mm, which meets the beam dynamics requirement.

RF design of a prototype of CDS-C for high-power test is also finished. Future works will include wakefield measurements with beam and high power tests in this prototype structure.

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